Power processors for interfacing renewable energy resources to a DC-bus

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Nowadays, most governments around the world accept that alternative and, especially, renewable energy sources have to be part of the energy mix. The realisation that the world cannot rely on fossil fuel sources forever has added to the urgency to find other viable energy sources.

The key obstacle to exploiting most renewable energy sources is that their raw output is not well suited to direct connection to the existing transmission and distribution grids. The output is also not suitable for feeding practical loads. The output voltage levels of these sources are too low to feed conventional loads. Furthermore, output voltage levels vary widely as irradiation levels, ambient temperature, wind or wave speeds vary. Renewable energy sources include solar, wind, tidal, hydro-, geothermal and biomass energy. Solar, wind and tidal resources are intermittent and statistical. Therefore, it is necessary to incorporate power processors to condition the outputs of systems that are used to convert these resources into electrical energy before supplying most practical loads.

Energy from the sun can be harnessed in a variety of ways. Photovoltaic (PV) panels have been used to convert solar energy into electrical energy for a few decades now. The output voltages of commercially available PV panels are in the range of 6 V to 70 V. However, most commercially available solar PV arrays are built using 12 V or 24 V panels. PV panels' voltage-current characteristics are such that ambient and panel temperature influences the output voltage, whereas irradiation levels affect panels' output current.

Solar PV farms consist of groups of PV panel arrays. An array is constructed by connecting a number of PV panels in series to form a string, and several strings are connected in parallel to form an array. The number of panels connected in series to form a string and the voltage rating of an individual panel determines the array's rated terminal voltage.

An array's rated output current is the total sum of currents from all the strings connected in parallel. Most practical single-phase loads fed from inverters require DC-buses that operate between 300 V and 450 V. Three-phase loads, however, require the inverters to be fed at between 700 VDC and 800 VDC. An inverter is an electronic device or circuitry that changes direct current (DC) to alternating current (AC).

In order to meet DC-bus rated voltage, there is a need to have many PV panels connected in series to form a string. For example, at least thirteen 24 V panels would be required to realise a string with a terminal voltage of 300 V. The number of panels required more than doubles if 12 V panels are used or DC-bus voltage is increased to 700 V.

Given the physical size of a PV panel, a large area will be needed to erect a string of an array. Consequently, there is a very high likelihood that not all panels in a given string will be exposed to identical environmental conditions at all times. This is even more so when PV arrays are erected in highly built-up areas. In such environments, there is a possibility that the shadows of trees or buildings can affect only some at a given time. Even in instances where PV arrays are erected in open spaces, there are still chances of clouds, dust or a combination of the two only affecting some of the panels in a given string of an array. Furthermore, it is likely that the characteristics of the panels in a given string will not be perfectly matched due to the high number of panels involved.

When panels in a given string are exposed to different levels of solar irradiation because of shading or dust on some of them, their output currents will differ. This creates a problem due to the series connection of the panels. The result is that the string current will be equal to that of the panel with the lowest current. Inevitably, string power output is reduced. Because panel surface temperature affects the terminal voltage generated, the terminal voltages of parallel-connected strings that have their panels subjected to differing temperatures will differ, giving rise to voltage differences between parallel-connected strings. A shorted panel would also lead to differences in strings' terminal voltages.

Unless appropriate measures are taken at the design stage, the voltage differentials will cause one string to circulate current through another. This inevitably leads to additional power losses in the array and a reduction in the available output power. Moreover, an open-circuit fault in any one of the panels in a given string will cause that string to be lost. At the moment, most installations employ diodes to bypass any panel that has an open-circuit fault or is shaded. This avoids a situation where an entire string is lost due to open-circuit faults or a panel in the shade. Diodes are also connected in series with each string to prevent one string circulating current through another when their terminal voltages differ. The downside to this approach is increased cost, complexity and losses, as well as degraded overall system performance.

An alternative approach to overcome the shortcomings of PV arrays using long strings with many series-connected panels is to use shorter strings and increase the number of parallel connections to meet load power requirements. This method of array implementation makes it easier to group panels in a given string in much closer physical proximity, which reduces the chances of the panels in a string being exposed to differing environmental conditions. Consequently, such a configuration helps to keep an array's power output as high as possible, even when the panels are subjected to different environmental conditions.

The downside to this approach is that it is necessary to incorporate an electronic power processor to boost the array's terminal voltage to match that of the DC-bus feeding loads (assuming the DC-bus voltage is constant, irrespective of whether a long or short string is employed). The voltage-current characteristics of PV panels are such that, for a given set of environmental conditions, the amount of power that can be extracted depends largely on the

panel's terminal voltage. Moreover, for a given set of environmental conditions, there is a terminal voltage that leads to maximum power extraction from a panel.

As a result, it is routine to employ electronic power processors to ensure that maximum output power is tracked at all times. This is achieved by operating the power processor in such a manner that the panel's terminal voltage corresponds to the voltage that guarantees that maximum power is extracted from the panel. In most practical implementations, however, it is uneconomical to track the output power of each individual PV panel. Instead, it is assumed that all the panels have identical characteristics and that the environmental conditions to which all panels are subjected are identical.

This approach has the drawback that localised maximum power points of individual panels are not necessarily tracked and, as a result, the maximum output power may not necessarily be extracted. With fewer series-connected panels in a string, more accurate tracking of maximum power becomes possible, which leads to higher output power. The power processor needed for maximum power point tracking (MPPT) can also be utilised to boost the array's terminal voltage to match that of the available DC-bus if an appropriate converter topology and control strategy are selected or identified.

At the moment, implementations of PV arrays and the converter topologies employed to build power processors for implementing MPPT are not capable of very high-voltage boost ratios, and when they are, they have a number of shortcomings. Some of these shortcomings include complex magnetic component design, low efficiency, complex control schemes and high input- and/or output-side current ripple operation.

The latter requires the use of filter circuits comprising capacitors and inductors. Moreover, PV panels and, generally, most of the renewable energy sources are not suited to operating with fast current dynamics, for example, those encountered when supplying pulsed loads or when feeding power electronics converters that draw pulsed currents or currents with high ripple content. The voltage-current characteristics of PV panels are such that supplying fast-changing current will cause the terminal voltage to deviate from the nominal value, and in turn will lead to output power variations.

Operating under such conditions makes it difficult for the panel to deliver maximum possible output power. To ensure MPPT, even when supplying loads with fast-changing currents, it is necessary to use electrolytic capacitors as sources of the fast dynamic currents. Electrolytic capacitors are known to have a few shortcomings. Some of these include high cost, bulky size and short lifetimes when operated in high ambient temperature environments. A need therefore exists to develop efficient, compact and affordable high-voltage boost ratio power processors that do not draw currents with high harmonic content.

During the last few of years, the Power Research Group in the Department of Electrical, Electronic and Computer Engineering at the University of Pretoria has developed power processors that are suitable for interfacing renewable energy sources with the DC-buses used to feed loads. These power processors are capable of operating with high-voltage boost ratios, high efficiency, and low input- and output-side current ripple. The research has led to the development of power processors with voltage boost ratios of more than 20 times, while maintaining full-load efficiency above 77%. This performance is much better when compared with the high boost ratio power processors that are currently available.

Most transformerless topologies are not capable of boost ratios of more than ten times, and efficiency is rarely above 80%. On the other hand, those with transformers draw pulsed currents with a high ripple content. The power processors that were developed had an efficiency rate higher than 85% for boost ratios of 17 times. This means that the power processors can be used to interface a single 24 V PV panel with a 400 V DC-bus or a 48 V panel with an 800 V DC-bus. Compare this with the need to connect at least seventeen 12 V panels in series to realise a 400 V output. Low input- and output-side current ripple operation makes it possible to build power processors with only small capacitors, which makes them cheaper, more compact and lighter, while improving performance.

Some of the team's research findings have been published in the *Journal of Power Electronics,* as well as in the *Proceedings of the IEEE IECON 2014 Conference*.

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